3GPP TSG-RAN WG1 #88 **R1-1703208**
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Source: National Taiwan University

Title: LDPC codes for both eMBB and URLLC data channels

Document for: Discussion

1 Introduction

In RAN1 #86bis and #87meetings, it was agreed to use LDPC codes for eMBB data channels and polar code for control channels. When considering the URLLC, the service requirements at higher layer are different from those of eMBB. However, at the physical layer, it is expected that URLLC data will use the same channel as the eMBB data. Therefore, the simplest option is to use a single channel coding technique for eMBB and URLLC, regardless of higher layer service type being eMBB or URLLC [1]. However, the channel coding technique would have to satisfy the performance requirement for both eMBB data and URLLC data. The URLLC reliability requirement is specified in TR 38.913 [2], where the target BLER is 10^{-5} within 1 ms for payload size of 32 bytes. In this contribution, we discuss and evaluate the use of LDPC codes for eMBB and URLLC data channels. We made an attempt to evaluate code performance down to the target BLER of 10^{-5}.

In the RAN1-meeting AH_NR, the conclusion is reached that further study be prioritized for LDPC codes with respect to the EMBB and URLLC data channel [3].

Conclusion:

- *At least the following criteria are considered for LDPC design comparison in addition to BLER performance*
  - *Implementation complexity*
  - *Latency*
- *Companies are encouraged to provide at least the following for the base matrix for the considered code rates:*
  - *Zmax*
  - *Total number of edges*
  - *Maximum row weight*
  - *Maximum column weight*
- *FFS if/how to define and compare numbers of (quasi) layers*

Based on these conclusions and agreements, we discuss our evaluations drawn by double QC-LDPC codes with degree-3 for eMBB and URLLC data channels. These codes would follow (N_{max}, K_{max}) requirement.

2 Design Considerations

- **Degree distribution and hardware complexity**

The complexity of LDPC decoder can be estimated based on the typical min-sum algorithm (MSA). As shown in Algorithm 1, the MSA provides the typical operations and explains how LLR values exchange between bit nodes and check nodes. There are two *for-loops* within each iteration: one loop is from check node to bit node, and the other from bit node to check node. The common parts are factors such as addition/subtraction, scaling and degree. The degree distribution is specified by the parity check matrix, and the hardware flexibility needs to support all the degree arrangements. So the degree profile such as total number of degrees, the max/min and row/column weights in QC-type should be listed and compared. To support the LDPC codes for URLLC and eMBB data channels, the degree distribution should be carefully design to lower the hardware complexity and improve decoding efficiency.

Algorithm 1 Min-Sum algorithm

Require: Decoding LR_i^{ch} using parity check matrix $\mathbf{H}$ with (N_v, N_c, Deg_v)

while $0 < iter \leq max\_iter$ **do**
  for $i = 1$ to N_v **do**
    $LR_i \leftarrow LR_i^{ch}$
    for $j = 1$ to Deg_v **do**
      // $LR_{i,\sigma(j)}$ is from min1,min2,min1loc.
      $LR_i \leftarrow LR_i + LR_{i,\sigma(j)}$
    end for *//variable node update*
    $V_i \leftarrow \Phi(LR_i)$ *// hard decision*
    check whether syndrome is all-zero or not.
    for $j = 1$ to Deg_v **do**
      $LR_{v2c} \leftarrow \alpha(LR_i - LR_{i,\sigma(j)})$
      use LR_{v2c} to update min1, min2, min1loc.
    end for *// check node update*
  end for
end while

Observation 1 : The number and arrangement of degrees in all matrix dominates the hardware complexity and decoding efficiency.

- **Channel coding for URLLC and eMBB data channels**

We agree on Ericsson's viewpoint in R1-1700115 [1].

"*When considering the data channels of URLLC, the service requirements at higher layer is different from those of eMBB. However, at the physical layer, it is not expected that URLLC data will use a different channel than eMBB data. That is, both URLLC data and eMBB data are both carried by NR PDSCH on the downlink, and are both carried by NR PUSCH on the uplink. This is similar to LTE, where PDSCH (and PUSCH) carries higher layer data of different service requirements.*

Thus, similar to LTE, the simplest option is to use a single channel coding technique for PDSCH and PUSCH, regardless of higher layer service type being eMBB or URLLC. That is, the simplest is to use LDPC codes for both eMBB and URLLC, as long as LDPC codes can sufficiently serve the needs of URLLC "

Observation 2: The LDPC codes protomatrix in URLLC data channel can be applied to the eMBB data channel.

- **Parity check matrix structure**

The PCM structure with sub-matrices (A, B, C, D, E) [4] has been presented to describe the dual-diagonal and diagonal base graph. The PCM structure does not promise any effective and attractive advantage such as lower error floor or lower complexity. We observe these agreements will give higher degrees than these of double QC LDPC code with degree-3. Moreover, code-rate flexibility requirement would leads to higher hardware complexity in these sub-matrices(A, B, C, D, E) agreements. These sub-matrices imposes constraints for parity matrix design flexibility rather than facilitating perfromance.

Observation 3: The agreements of protomatrix structure design should aim at low-complexity and high reliability rather than design constraint.

3 Performance Evaluations

We propose double QC-LDPC codes for coding candidates[5]. The encoder of double QC-LDPC matrix is equipped with a unique structure based on circulant of circulant matrix and is a special form of QC-LDPC. The double QC-LDPC PCM matrix with regular row weight of 3 and thus very low total number of degrees which leads to low-complexity codec and ease for implementation. While low and regular degree-3 in PCM, the BLER down to 10^{-5} can be achieved for block sizes 128 to 8192 and code rate from 1/5, 1/3, 1/2, .. to 8/9. The typical BLER performances is depicted in Figs. 1 to 8. The regular degree distribution in the PCM facilitates fast and efficient decoding for low latency. The same protomatrix can be applied to both eMBB and URLLC data channels.

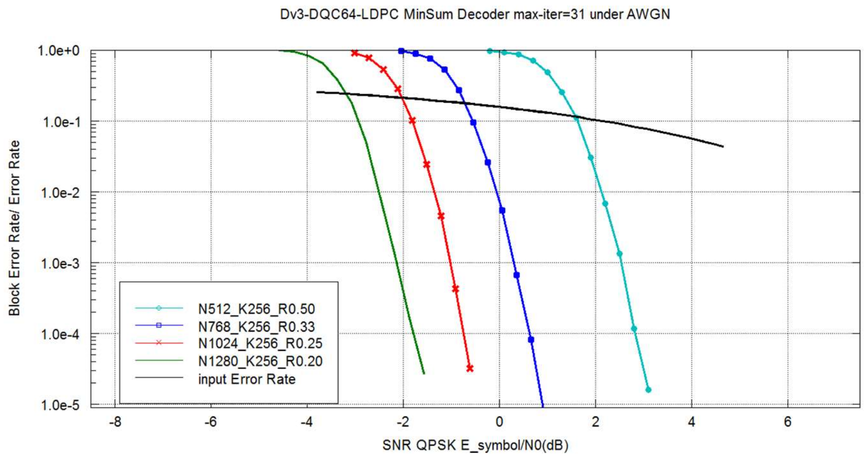

Fig. 1. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 256.

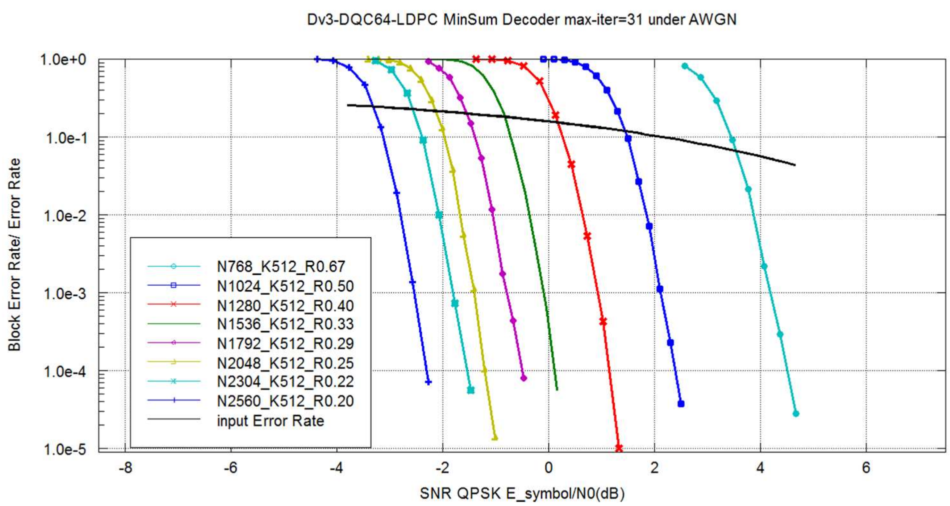

Fig. 2. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 512.

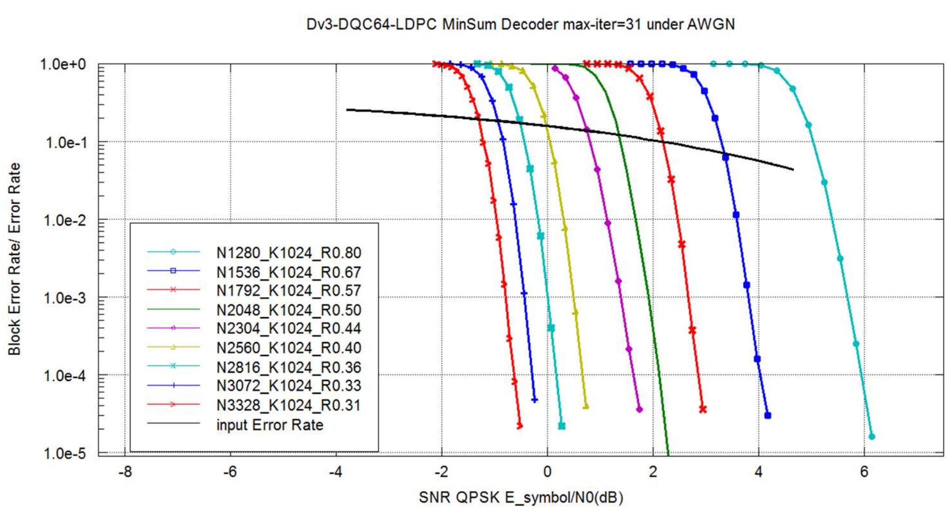

Fig. 3. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 1024.

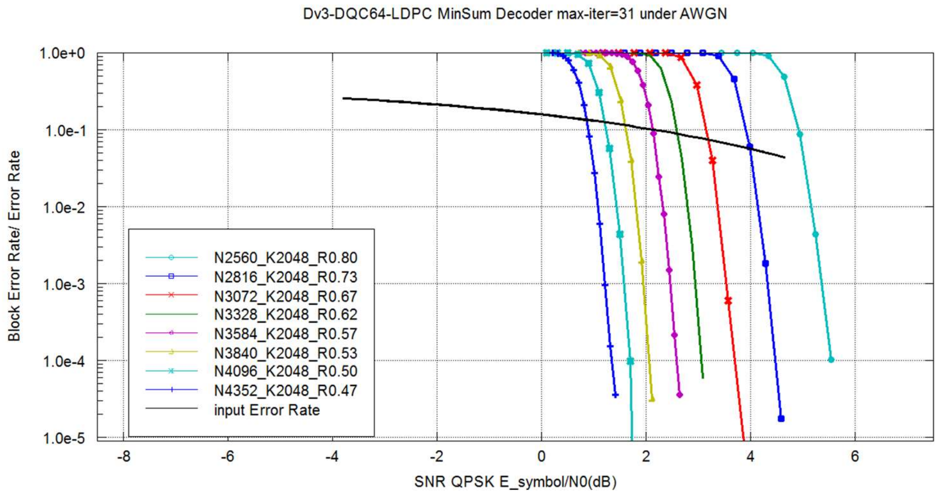

Fig. 4. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 2048.

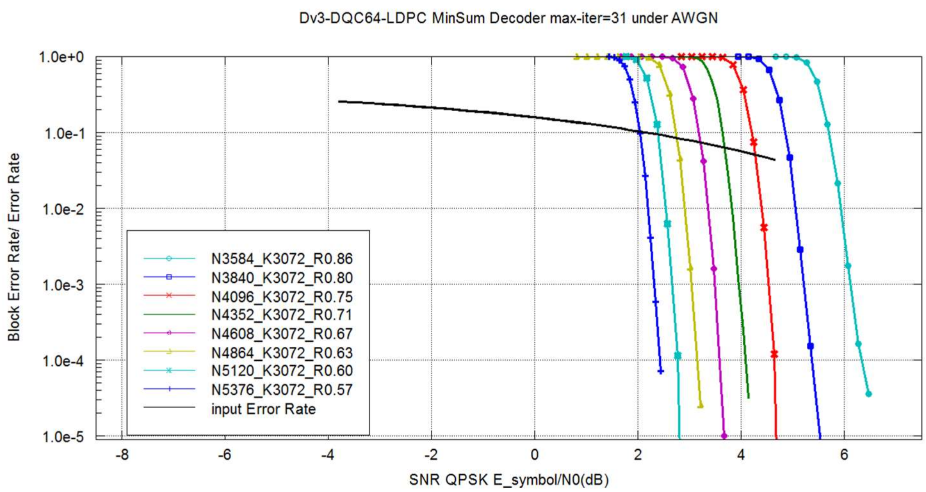

Fig. 5. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 3072.

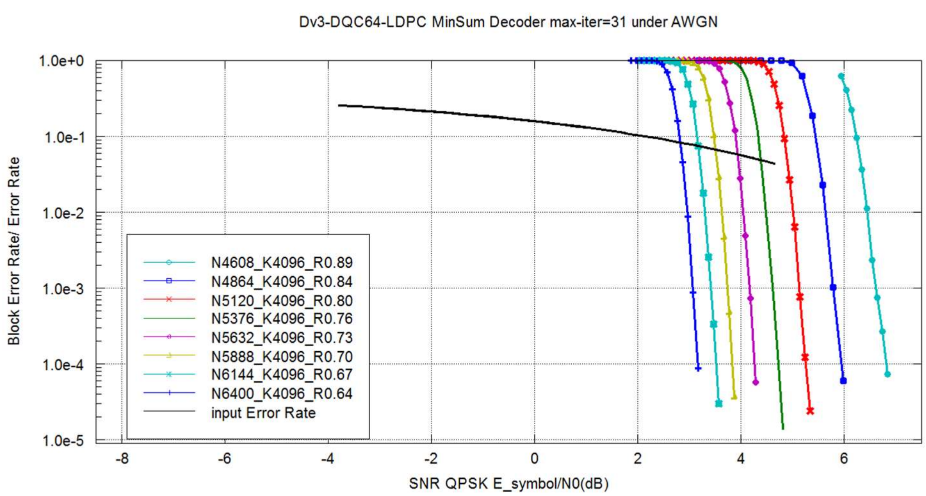

Fig. 6. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 4096.

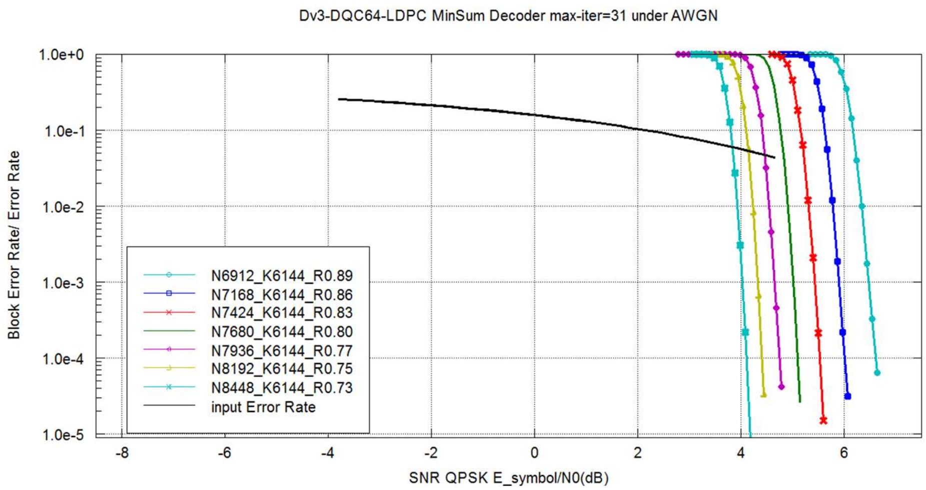

Fig. 7. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 6144.

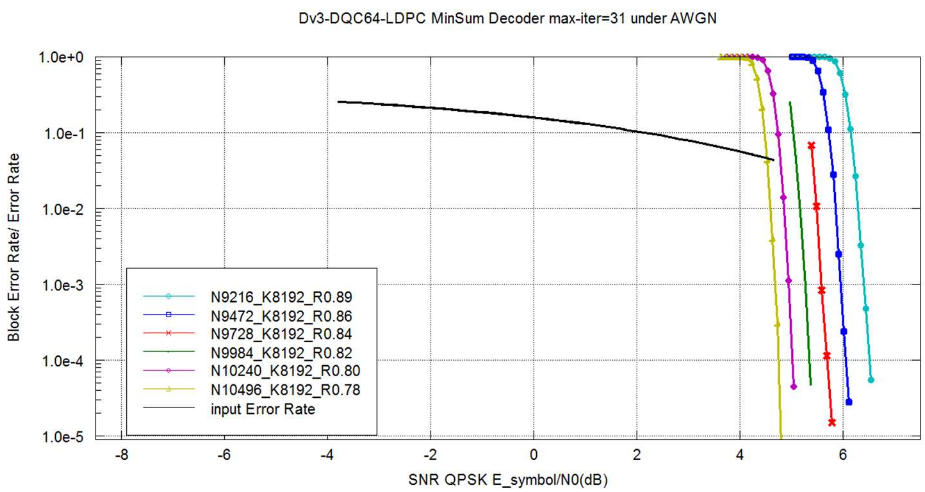

Fig. 8. DQC-LDPC codes with circulant size z =64 with PCM degree-3 and K = 8192.

4 Conclusions

Proposal 1: A single channel coding technique for eMBB and URLLC in the physical layer should be adopted.

Proposal 2: LDPC codes should be adopted for eMBB and URLLC data channels.

Proposal 3. The LDPC codes protomatrix in URLLC data channel can be applied to the eMBB data channel.

Proposal 4: The total degrees in parity check matrix can be a numerical index for complexity evaluation.

Proposal 5: Double QC- LDPC codes with degree 3 is suitable for eMBB and URLLC data channels which leads to low complexity and provides sufficiently reliable performance for BLER down to 10^{-5}.

5 References

[1] R1-1700115, "Channel coding techniques for URLLC", Ericsson, 3GPP RAN1 meeting AH_NR,Spokane, US.
[2] 3GPP TR 38.913 Study on Scenarios and Requirements for Next Generation Access Technologies.
[3] R1-1701384, "Chairman's notes of AI 5.1.5 on channel coding", 3GPP RAN1 meeting AH_NR, Spokane, US.
[4] R1-1701289, "WF on parity matrix structure", Samsung, 3GPP RAN1 meeting AH_NR, Spokane, US.

[5] R1-1700645, "Evaluation on double QC-LDPC codes with degree-3 for URLLC", National Taiwan University, 3GPP RAN1 meeting AH_NR, Spokane, US.